SYSTEMS ENGINEERING RESEARCH CENTER

System of Systems Analytic Workbench – 2017

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SUMMARY OF ACHIEVEMENTS

Our work in RT-178 has continued tool development of the System of Systems Analytic Workbench (SoS-AWB) and transitional activities with key collaborators. The tools include: System Operational Dependency Analysis/System Developmental Dependency Analysis (SODA/SDDA), Multi-Stakeholder Dynamic Optimization (MUSTDO), System Importance Measures (SIMs), and Robust Portfolio Optimization (RPO).

The workbench provides a means of addressing SoS practitioners' 'archetypal questions' in scenarios where size and/or interdependencies between systems are high. The workbench also enables analysis of *capability* and *risk* during the conduct of SoS evolution. Our common use case demonstration problem involves a Naval Warfare Scenario (NWS) that is based on the architecture of the Littoral Combat Ship (LCS). Each of the tools has used this common case study to illustrate the value in each tool performing various types of SoS level architectural analysis, as evidenced by prior literature and extensive documentation for predecessor RT-36, RT-44b, RT-108, and RT-134 tasks.

While continuing research on each of the methods, our FY17 RT-178 effort emphasized transitioning of the AWB for test in practical settings with our key collaborator(s), and dissemination to the broader community in terms of two main deliverables of a TED-style talk on the SoS-AWB, and, a white paper on reflections of a successful SERC project and directions for future projects. The following summarizes main accomplishments during our period of performance for this research task.

FURTHER DEVELOPMENT OF SOS-AWB TOOLS

We have extended each tool in the SoS-AWB and refined them through our exchanges with collaborative partners. Primary changes and value added in the methods of the SoS-AWB involve the following:

1. System Operability Dependency Analysis (SODA)/System Development Dependency Analysis (SDDA)
    a. Developed code for cut-sets and path-sets analysis for networks under analysis by user
    b. Developed code for analysis of failures in subsets of nodes of various size
    c. Developed code for analysis of range of failures and sorting of resulting operability in low, medium and high ratings
    d. Developed code for delay propagation (both cyclic and acyclic conditions)
    e. Developed a set of questions to guide modeling when data not available
    f. Development of standard dependencies with combinations of low-medium-high parameters

COLLABORATOR EXCHANGES AND RESEARCH DISSEMINATION

SERC- We have continued our collaborative exchanges with various members of SERC community as and when needed towards development and/or dissemination of the SoS-AWB.

Johns Hopkins University Applied Physics Laboratory (JHUAPL) – Transition of SERC Analytic Workbench Technology into Government Service by JHUAPL. The application effort involves modeling an existing messaging network to perform real-time situational awareness. The Analytical Workbench's combination of dependency metrics (strength, criticality, and impact) will be leveraged within their own model of system effectiveness to measure network performance in real-time. These models will then be linked to a visualization/dashboard system that will allow operators to quickly and graphically determine consequences to related components based on the dependencies. We have attached the *JHUAPL-SERC-Article.pdf* that covers the scope of technology transfer for the SoS-AWB.

NASA Marshall Space Flight Center - Cooperative agreement in place to use methods in SoS-AWB (RPO, SODA, SDDA) to analyze space exploration architectures. Students under project utilized SODA and SDDA to analyze dependencies for systems and capabilities involved at various level of abstraction of the Mars exploration architectures.

Naval Surface Warfare Center Crane (NSWCC) – Collaborative work with NSWCC on use of SODA/SDDA for analysis of security missions. Another parallel project within Crane (in collaboration with Prof. Shimon Nof at Purdue) involves research maturation of Complex System/System of System technologies for architecting, evolving and rapid decision-making.

TED-Style talk – We have generated a TED-style talk video that will be delivered to the SERC at the end of this performance period (31st August 2017). Our video highlights the background, purpose, abilities and contributions of the SoS-AWB toolset to SoS engineering.

White Paper – We have prepared a white paper that details reflections of a successful SERC project and directions for future projects. The document contains insights on enablers, barriers and features of making a SERC project successful, based on experiences of the Purdue SoS-AWB efforts across multiple funded RT-efforts.

Software Dissemination

- Work under prior RT's have established an online instantiation of the Purdue SoS-AWB. We are happy to report that as of this report, we have **115 users thus far, with a total of ~1323+ runs of the SoS AWB.**
- Our software has been transitioned to Naval Surface Warfare Center Crane (NSWCC) for use in the efforts, as described in the prior section; this transition includes code transfer of the SoS-AWB to NSWCC, for government based use, per terms of the software use agreement established with SERC.
- Our software has been transitioned to the Johns Hopkins University Applied Physics Lab (JHUAPL); JHUAPL has implemented their own version of the toolset based on the workings of the SODA/SDDA toolset.

Students Graduates - the following students have successfully graduated under this research effort:

Zhemei Fang (Ph.D. - August 2017)

Rakshit Chandrahasa (MSAAE – August 2017)

APPENDIX A: LIST OF PUBLICATIONS RESULTED

CSER 2017 – [published] "A robust portfolio optimization approach using parametric piecewise linear models of system dependencies," 15th Annual Conference on Systems Engineering Research (CSER), Redondo Beach, CA, March 23-25, 2017

IEEE Aerospace Conference [submitted] – *"Tool suite to support Model-Based Systems Engineering-enabled System-of-Systems analysis"*

INCOSE System Engineering [submitted] – "Resilient System-of-System Design using System Importance Measures"

IEEE Systems – [in revisions] *"Multi-Stakeholder Dynamic Optimization for Acknowledged System-of-Systems Architecture Selection"*

Acta Astronautica [submitted] *"Understanding Human Space Exploration as a System-of-Systems problem"*

INCOSE Insight Magazine Article – "An SoS Analytic Workbench Approach to Architectural Analysis and Evolution," Best **Article Award**

APPENDIX B: CITED AND RELATED REFERENCES [EXAMPLES]

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Dahmann, J. (2012). INCOSE SoS Working Group Pain Points. In *Proc TTCP-JSA-TP4 Meeting*. Retrieved from http://www.ndia.org/Divisions/Divisions/SystemsEngineering/Documents/NDIA-SE-MS-SoS_2013-08-20_Dahmann.pdf